Doppler and Pathloss Characterization for Vehicle-to-Vehicle communications at 5.8 GHz

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***Abstract*—Due to significant increase in vehicular accident and traffic congestions, vehicle to vehicle (V2V) communication based on the intelligent transport system (ITS) was introduced. However, to carry out efficient design and implementation of a reliable vehicular communication systems,a deep knowledge of the propagation channel characteristics in different environments is crucial, in particular the Doppler and pathloss parameters. Therefore, this paper presents an empirical V2V channel characterization and measurement performed under realistic urban, suburban and highway driving conditions in Brisbane, Australia. Based on Lin Cheng statistical Doppler Model (LCDM), values for the RMS Doppler spread and coherence time due to time selective nature of V2V channels were presented. Also, based on Log-distance power law model, values for the mean pathloss exponent and the standard deviation of shadowing were reported for urban, suburban and highway environments. The V2V channel parameters can be useful to system designers for the purpose of evaluating, simulating and developing new protocols and systems.**

I. INTRODUCTION

Nowadays, the idea of exchanging safety messages between moving vehicles has attracted significant attention as a means to reduce traffic congestions and fatalities. The main idea of vehicle-to-vehicle (V2V) communication is for vehicles to receive information about traffic and road conditions that would enable a variety of intelligent transportation systems (ITS) services such as traffic condition warning, pre-crash sensing, and wrong way driving warning, lane change assistance and congestion avoidance.

Channel characterization and modeling are of importance for designing and optimizing advanced wireless communication systems. Also, the design of all components of mobile communication systems, ranging from digital modulation schemes over channel estimation techniques up to higher layer protocols, is influenced by the propagation characteristics of the mobile channel. Furthermore, to carry out practical design of reliable V2V communication systems, a deep understanding of the influence of every single system parameter is of critical importance to DSRC system designers. Several research groups have considered vehicular communication aspects based on empirical measurement campaigns, in which the impact of various system parameters, such as pathloss and Doppler spread were investigated [1][2][3][4][5].

Karedal et al.[1] presented a pathloss modeling from a V2V channel measurements conducted in Lund, Sweden. Their pathloss exponent parameters are as follows; n=1.68 for urban, n=1.59 for suburban and n=1.77 for highway environments. Kunish and Pamp [2] reported test result of V2V measurement conducted in Germany. They derived pathloss exponent for the highway (n = 1.85) and Urban (n = 1.61) environment based on log-distance power law model. L.Cheng et al.[4] reported n=1.59 (based on linear regression) from a V2V channel measurement conducted using a prototype DSRC radio in suburban driving environments near Carnegie Mellon University in Pittsburgh, PA However, none of these measurement based pathloss modelling have been conducted in Australia.

V2V propagation channels displays higher Doppler spreads more than the traditional cellular radio channels, due to the high relative velocities between the TX and RX vehicles and due to the presence of moving scatterers (or multiple reflective objects) causes higher Doppler shifts in V2V channels. Doppler spread values between 100-300Hz have been reported in [2][6] for highway and in [7] for urban environment. Tan et al. [7] presented Doppler values close to 1000Hz for highway environments. Kunisch in [2] proposed that high mobility of the TX and RX and the scattering environment leads to a large variation of the Doppler spread during a measurement.However, none of these vehicular channel characterization based on measurement have been conducted in Australia.

Furthermore, due to the difference in topographical features of urban, suburban and highway environments from one country to another and even within the same country, there is a need to perform more V2V channel measurements campaign in order to provide a thorough knowledge of the V2V propagation channels at different locations that would allow for the development of a more efficient and reliable V2V propagation channel model. Therefore, exploring the vehicular channel in different places is a key research topic. This paper presents an empirical V2V channel characterization performed under realistic urban, suburban and highway driving conditions in Brisbane, Australia. We present the Doppler spread and the pathloss model for three different V2V environments.

This paper is organized as follows. In Section II, we describe the measurement design and setup, V2V environments, measurement scenarios and parameter settings. Section III, presents V2V channel characterization. In Section IV, we present the preliminary result of our Doppler analysis and pathloss modeling. In Section V, we compared the Doppler spread values and the pathloss exponent values derived from the measurement with published results. Lastly, the conclusion was presented in Section VI.

II. EXPERIMENT DESIGN

A. *Measurement setup*

The extensive measurement campaign was carried out using the cooperative vehicle-infrastructure systems (CVIS) platform [8] as on-board unit (OBU) transmitter and receiver. The CVIS platform is equipped with a CVIS communication architecture for land mobiles (CALM) M5 radio module implementing the IEEE 802.11p protocol and a global positioning system (GPS) receiver, which constantly logs the exact position of the vehicles. The Rooftop Antenna OBUs contains five individual antennas, a Dedicated Short Range Communication(DSRC) system , a global positioning system (GPS) antenna, a broadband GSM/UMTS antenna (named CALM 2G/3G in CVIS) and two broadband WLAN antennas (named CALM M5 in CVIS) as shown in Fig. 1 and Fig.2.

The DSRC system and GPS antenna are commercially available components which are integrated into the Rooftop Antenna Unit. The Rooftop Antenna OBUs were mounted on the roof of the first two test vehicles (Toyota Land cruiser Prado Jeep and a Toyota FJ Cruiser Jeep) at a height of approximately 1.95m above the ground as shown in Fig.3. On the next set of measurement, the two antennas were mounted on the roof of two commodore station wagon vehicles at height of 1.5m above the ground. The CVIS Rooftop Antenna for CALM M5 communication is a vertically polarized double-fed printed monopole and has radiation pattern close to isotropic, according to measurements in [9].

For all the measurements, the transmitter (TX) and receiver (RX) vehicles were driving in the same direction (convoy driving) with the TX vehicle leading the RX vehicle under mostly LOS conditions, where occasional obstruction of the LOS by other vehicles did occur. The transmitting vehicle was continuously transmitting User Datagram Protocol (UDP) frames while the receiver was recording and logging the received frame. The TX and RX device were constantly synchronized using two external U-blox EVK 6 GPS, which are locked to the NTP server. Each of the measurement scenarios considered lasted for about thirty minutes and each scenario was repeated ten times.

For each transmitted packet, the RX OBU records its receive signal strength (RSSI), receive noise power, data rate, time and location where it was received. All measurements were performed at a center frequency of 5.8 GHz under real traffic conditions with the test vehicles speed between 40-60 kmph for urban, 50-80 kmph for suburban and 80 and 100 kmph for highway scenarios. The software and hardware required for the system configuration are listed in TABLE I.

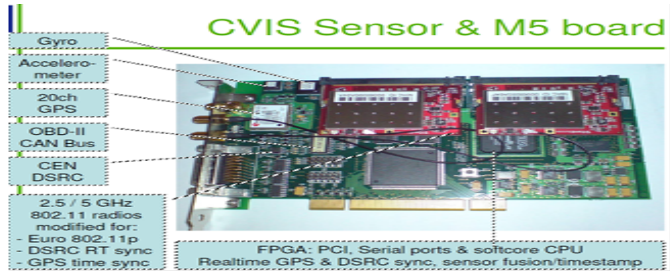

Fig. 1: CVIS CALM M5 chipset

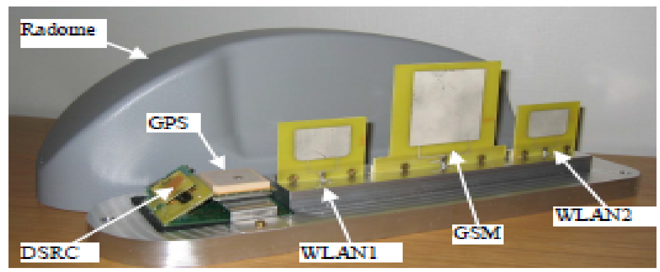

Fig. 2: CVIS Antennas

Fig. 3: Measurement vehicles

TABLE I: Hardware and software used for system configuration

Components	Details
CVIS OS	Linux / Ubuntu 9.0 (kernel 2.6.22)
CALM M5 DRIVER	Mad-Wi-Fi-driver modified version for 802.11p that supports radio tap header information generation.
GPS daemon	Monitoring daemon that provides a TXP/IP port, and receives data from a GPS receiver and provides the data back to multiple applications.
Wireshark and dumpcap	Free open source packet capture and analyser software tool. Monitor mode (passive) interface logs packet with radio tap header.
NTP daemon	Catches information from GPS daemon and synchronizes system-clock with GPS clock at system start-up and to correct drift.

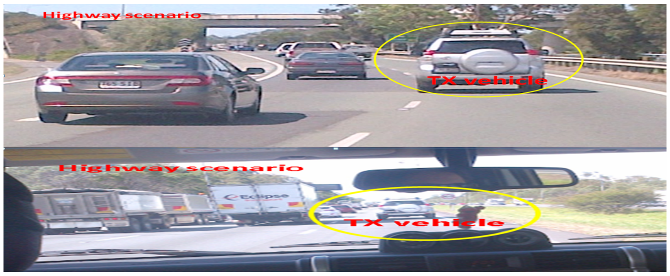

Fig. 4: On board view from the RX vehicle for the highway scenario

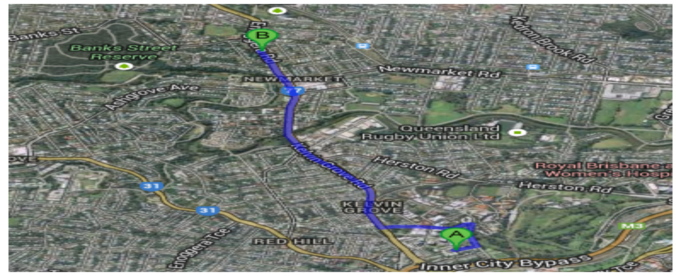

Fig. 5: 3D view of the Urban environment

B. Measurement Environments

The main features of vehicular environments that are necessary to be considered during V2V propagation channel characterizations include; the type of environment (rural, urban, suburban and highway), the speed of the vehicles, the vehicular traffic density and the direction of movement of the test vehicles (convoy, opposite direction). Generally, the urban environment has more traffic density and surrounding objects (scatterers) such as houses and other vehicles, while the highway environments have higher vehicle speed and fewer obstructions. Our measurements were conducted between 9.00 am and 4:00 pm daily for two weeks with the TX and RX vehicle driving in the same direction. The TX vehicle was leading the RX vehicle during the convoy driving scenario.

In our measurement, we have considered three V2V scenarios; highway, suburban and urban scenarios.

The highway scenario in Fig. 4 has three lanes in each direction. The vehicle speed varies from 80 to 105 kmph. The roads are demarcated with concrete walls; however, there are some areas that are separated with metallic pipes. It has few surrounding trees and vegetation. It has medium traffic density. The routes followed by the TX and RX vehicles is between Chermside to North Lakes, Brisbane.

The urban scenario contains high traffic density and three lanes in each direction. It has many traffic lights which results in intermittent driving periods. It has many surrounding houses, trees and obstructing objects. The speed here varies from 40 to 60 kmph. A 3-D view of the measurement environment are shown in Fig. 5.The blue lines shows the route followed by the TX and the RX vehicles.The routes followed by the TX and RX vehicles is between Kelvin Grove Road and Enogerra road, Brisbane.

The suburban scenario is a two lane street and has few surrounding buildings, trees, vegetations and low traffic density. The routes followed by TX and RX vehicles is between Kelvin Grove and chermside, Brisbane.

C. Experiment scenarios and paramater settings

All the measurements were carried out in real driving and traffic conditions. The CVIS OBU was transmitting continuous UDP frames with the following parameter settings shown in TABLE II. All of the successfully received transmitted data packets at the receiver OBU were stored on the local computer along with the recorded GPS data. Location statistics such as distance and speed are computed from NMEA GPS data. During the measurement, the vehicles pass through multiple kinds of local scatterers, some of these scatterers such as buildings and trees are stationary, while others such as vehicles and pedestrians are in motion.

TABLE II: V2V measurement parameter settings

Parameters	Settings
Internet connectivity	Fast 4G Wi-Fi Modem
Transmit power	5, 10, 15, 27 dBm
Data rate	3, 6, 9, 12, 18, 24 Mpbs
Packet length	200, 787, 1554 bytes
Centre frequency	5.8 GHz
RSSI noise power	-107, -108 dBm

III. V2V CHANNEL CHARACTERIZATION

A. RMS Dopper spread

The Root mean square (RMS) Doppler spread is an important characterization method for the time variability of the channel. The RMS Doppler spread thus characterizes the channels frequency dispersion or, equivalently, the time selectivity of the channel. Channel can be considered to be constant over a timescale that is the inverse of the Doppler spread known as the coherence time. The Doppler spread is a quantity that is of interest in itself for OFDM systems, because it leads to inter-carrier interference, as part of the signal emanating from one subcarrier is not in the spectral nulls of the adjacent subcarriers anymore [10]. Lin Cheng et al.[4] [11] presented an experimental study of the Doppler and coherence properties of V2V wireless channels at 5.9 GHz in both rural and highway environments. They observed that the average Doppler spread was linearly dependent on the effective speed; defined as the square root of the sum of the squares of the ground speeds of the two vehicles. They found that small-scale fading is not caused by the simple shift of the frequency of the signal with relative velocity, but is due to this Doppler spread, as the received signals of different frequencies go in and out of phase with one another. They observed that the Doppler shift of the LOS component was exactly explained by the relative speed of the TX and RX vehicles. Hence, the linear correlation of the RMS Doppler spread with the effective speed of the TX and RX vehicles, Veff as follows;

$$F_{Drms} = (\frac{1}{\lambda})\sqrt{\frac{V_{TX}^2 + V_{RX}^2}{2}} \quad (1)$$

where;

$$V_{eff} = \sqrt{V_{TX}^2 + V_{RX}^2} \quad (2)$$

$$F_{Drms} = (\frac{KV_{eff}}{\lambda\sqrt{2}}) \quad (3)$$

The empirical dependence of the Doppler spread on the effective velocity was found to be;

$$F_{Drms} = (\frac{0.428}{\lambda\sqrt{2}})V_{eff} + 11.5 \quad (4)$$

Where K value is predicted to be equal to 1 by the scattering ring model as shown in [11], whereas measurement in [12]has shown that the value of K =0.428. =50.81mm is the wavelength of the electromagnetic wave at 5.9GHz. Note that the relative velocity was not used in the calculation of the Doppler spread because the small-scale fading is not caused by the simple shift of the frequency of the signal with relative velocity. Hence, our Doppler spread and coherence time were deduced from the effective speed based on Lin Cheng experiment. Existing models that assume stationary scattering objects account some, but not all of the observed features in these spectra. The effects of moving objects must be taken into account particularly vehicles in oncoming lanes, owing to their large relative velocity and often close proximity.

B. Pathloss modelling

Pathloss is defined as the difference between the effective transmit power and the received power both in dBm. When the TX and RX are isotropic antennas the antenna gains .We have different pathloss models e.g. free space, two ray model and Log-Distance Power law model. The free space propagation model assumes a clear, unobstructed line of sight (LOS) path between transmitter (TX) and receiver (RX). The two-ray model is one of the simplest propagation models which consider a direct path and a reflected path from the surface of the earth. Pathloss can be represented as;

$$PL = 10log_{10}\frac{P_t}{P_r} = -10log_{10}\frac{\lambda^2}{(4\Pi)^2 d^2}; PL = Pt - Pr \quad (5)$$

where Pr is the transmitted power, G_t and G_r are the TX and RX antennas gain respectively. λ is the wavelength of the electromagnetic wave at the operating frequency, d is the separation distance between the TX and RX. Pathloss is represented as a positive quantity measured in dB and it is defined as the difference between the effective transmit power and the received power both in dBm. When the TX and RX are isotropic antennas, the antenna gains G_t=G_r=1. The measurement presented here were conducted at Pt=27dBm, except otherwise stated.

The pathloss exponent n indicates the rate at which the pathloss increases with distance. The value of n depends on the specific propagation environment. For example, in free space, n is equal to 2, and when obstructions are present (e.g. outdoor), n will have a larger value between 2 to 4. The lower the value of n, the better the propagation.

Our empirical pathloss modelling was based on the log-distance power law model. The generic form of this log-distance power law pathloss model which needs a total of three parameters is given by;

$$PL = PL(d_0) + 10nlog_{10}(\frac{d}{d_0}) + X_\sigma \quad (6)$$

where n is the path loss exponent estimated by linear regression in the logarithmic scale using the least square regression procedure. $PL(d_0)$ is the pathloss at a reference distance d_0 and X_σ is zero-mean normal distributed random variable with the standard deviation, σ .

IV. PRELIMINARY MEASUREMENT RESULTS

The preliminary measurement campaign has taken place in three different V2V environment; Urban (Kelvin Grove (KG) to Enogerra Road, 6km drive), Suburban (KG to Chermside, 20km drive) and Highway (Gympie to Northlakes, 40km drive) environment in Brisbane, Australia. All the results presented here were calculated as an average over at least 10 measurement runs. Fig.6 illustrates the evolution of the TX/RX separation distance and relative speed, Doppler shift, effective speed, and signal to noise ratio (SNR) over UTC (hour:minutes) time when the experiment was conducted, in a record of 1080s. The SNR was derived from the RSSI and Noise power captured using the wireshark software tool.

We observed a great correlation between the separation distance and the relative speed between the two vehicles; we suspect that this was due to the tendency of the vehicle drivers to maintain greater separation distance when the vehicles are at higher speed, which results in the vehicle speed being higher at larger separation distance.

We found some moments where the relative speed between the vehicles was almost zero; this corresponds to a stop situation due to traffic lights.

Fig. 7 shows the 2-D view of the distance traveled during one of the measurement run, in the highway environment at a P_t = 16 dBm, Data rate = 12 mbps and Packet length = 200 bytes. This figure was derived from the longitude and latitude location information extracted from the GPS. The red line shows the path followed by the transmitter vehicle while the blue lines illustrates the path followed by the receiver vehicle.

A. RMS Dopper spread and Coherence time

Vehicular channels tend to show higher Doppler spread than the conventional cellular radio channels because of the high relative velocity between the TX and RX and the scatterers. The Doppler spread and coherence time was evaluated from the effective speed of the TX and RX vehicle based on the Doppler analysis in [4] [11].

From the Table III, presents the results of the Doppler spread, coherence time and pathloss exponent value derived

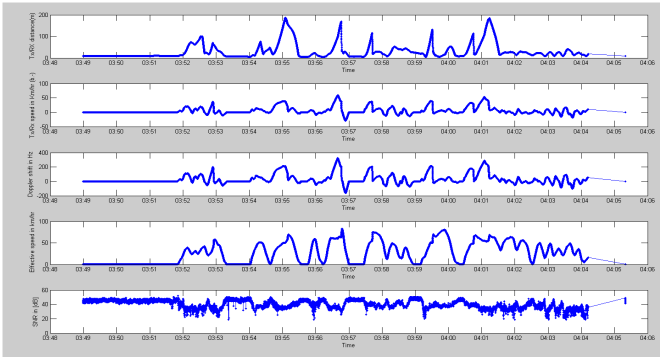

Fig. 6: (a)Tx/Rx separation distance, (b) Tx/Rx relative speed (c) Doppler shift (d) Tx/Rx effective speed (e)SNR

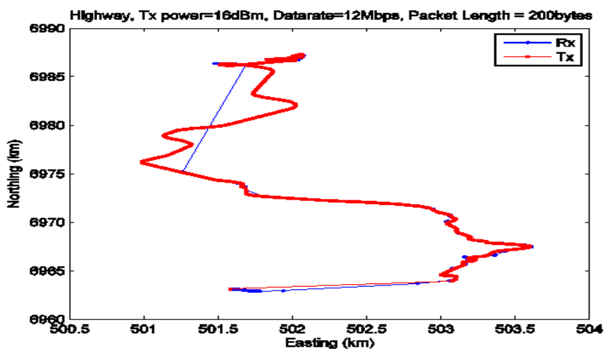

Fig. 7: 2-D View of the distance travelled by TX and RX in Northing and Easting (km)

from our V2V channel measurement campaign for urban, suburban and highway environments. From the table the mean maximum Root Mean Square (RMS) Doppler spread value evaluated from our measurements are 149Hz , 162Hz and 247Hz for urban, suburban and highway scenarios respectively.We observed that in general the highway scenarios results the highest RMS Doppler spread and the lowest RMS coherence time compare to the urban and suburban environments. This may due to high mobility of the TX/RX vehicles which increases the effective velocity and the presence of other well reflecting surface such as metallic demarcations and concrete walls in our chosen highway scenario.

Also note that the urban scenario has a lower Doppler shift compared to the suburban scenario, which may be due to the presence of many traffic lights and high traffic density in the urban environment which leads to occassional stopping of the vehicles which reduces the effective velociy , hence leads to reduced Doppler shift. The RMS Doppler spread tends to remain constant (low)in scenarios where the TX and RX vehicles are driving in the same direction; at the same speed and where the MPC are not strong.

It would be of interest to relate our V2V channel measurement to the OFDM transmission scheme proposed for use in vehicular communication. OFDM modulation involves the multiplexing of many carriers that are orthogonal to each other.

TABLE III: Doppler spread, coherence time and pathloss model parameters for different environments.

Scenarios	Pathloss exponent (n)	Doppler spread	Coherence time
Highway	1.77	247 Hz	1.57 ms
Urban	1.68	149 Hz	2.1 ms
Suburban	1.53	162 Hz	1.85 ms

Hence, it is appropriate to combat Inter-carrier Interference (ICI). When the signal on the carrier is affected by Doppler spreading, it can leak into the adjacent carriers resulting to ICI. Therefore, to prevent ICI, the carrier spacing must be larger than the maximum Doppler spread.

From the channel measurement result, the maximum Doppler spread is approximately 250Hz for the highway scenario, hence the proposed 156 KHz carrier spacing employed in the proposed IEEE 802.11p DSRC for the V2V communication would ensure negligible ICI. However, the above assumption is not true. As the 802.11p is a modified version of 802.11a standard, the channel estimation occurs at the beginning of a packet and this estimate is used for the remainder of the packet. Since our test results presents a coherence time around 2 ms at 5.8 GHz frequecy and packet duration of 50ms. The packet duration (Ts) is larger than the Coherence time (Tc) of the channel, this leads to fast fading or time selective fading because (Ts is far greater than Tc).

Therefore, the channel varies within one OFDM packet; hence the channel estimation would not remain valid for the duration of one packet used in the wireless network. This suggests that either very short packets less than the channel coherence time should be used or that more dynamic channel estimation with tracking technique should be implemented to ensure better performance and maximum reliability of the system.

B. Pathloss Modelling

In this section we analyze the Pathloss in terms of the received power(RSSI) versus the TX-RX separation distance for three different vehicular environments; urban, suburban and highway. The pathloss exponent n indicates the rate at which the pathloss increases with distance. The value of n depends on the specific propagation environment. For example, in free space, n is equal to 2, and when obstructions are present (e.g. outdoor), n will have a larger value between 2 to 4. The lower the value of n, the better the propagation.

The figures ; Fig.8, Fig.9 and Fig.10 shows the scatter plot of the received power versus the separation distance between TX and RX in logarithm scale. The solid red lines are the result of linear fit based on least square method to the measured data (blue color) for each of urban, suburban and highway scenarios. The pink line is the result of the free space pathloss model ,n=2 and the green curve is the theoretical two ray pathloss model at transmit and receive antenna heights of

1.5m . For each of these scenarios, we derived the pathloss exponent using the log-distance power law model. $PL(d_0)$ is the extrapolation of the pathloss slope in the different scenarios considered. For all scenarios, it is interesting to note that the greater values of the path loss exponent at smaller separation distances correspond to those paths where the LOS (direct path) was strongly obstructed by moving scatterers (e.g. nearby vehicles) and other sources of interference.

In the urban scenario, as shown in Fig.8, we derived the pathloss exponent of n=1.68 . The urban measured result show a random variation which is due to the ground reflection being obstructed for long durations, usually by the concrete wall that separates the directions of travel and occasionally by other traffic.It could be seen that the measured data have a similar pattern as the theoretical two ray model. The measurements were conducted under LOS conditions, in the morning hours when there are many obstructing vehicles on the road, hence resulting in the received signal consisting of a dominant LOS component and a single ground reflection to form the multipath effects. Hence, LOS and one ground reflection dominates the multipath effects on the received signal.

For the suburban environment as shown in Fig.9, we derived pathloss exponent, n=1.53.

For the highway scenario in Fig.10, the value obtained for the pathloss exponent, n=1.77 . From the results, the greatest n value occurs in the highway scenario where the vehicles speeds are higher with more reflections from metallic objects.

In the urban scenario where the blocking effect of the Tx-Rx link by surrounding vehicles more prevalentleading to a pathloss n=1.68. From the results, the n values are lower than the free space model (LOS paths) of n=2. In practice, pathloss exponents lower than 2 do not always imply propagation conditions that are better than the free space. The greater the pathloss exponent n, the lower the $PL(d_0)$ and vice versa. Pathloss exponent n lower than 2 relates to $PL(d_0)$ greater than 47.85 dB ($PL(d_0)$ for free space). In summary, this implies that even though the pathloss exponent is lower than 2, the total pathloss is greater than the pathloss in LOS conditions. This is in agreement to previously reported V2V measurements, where the measured pathloss exponent ranges from 1.5 to 1.9 [1] [2] [3] [4].

C. Comparing our proposed Doppler spread and pathloss model parameters with previously published results.

TABLE IV provides a comparison between the different Doppler spread and the pathloss exponents obtained from our measurements for the urban, suburban and highway environments and other previously published research works.

From the table, n, F_D and T_c are the measured pathloss exponent,Doppler spread the coherence time values respectively. While n^1 and ${F_D}^1$ are the published pathloss exponent and Doppler spread.

For highway scenario, we got an RMS Doppler spread of 250Hz at a relative speed of around 14m/s and an effective speed of approximately 40m/s. Lower values of Doppler spread, 92 Hz and 120Hz have been reported in [2] and

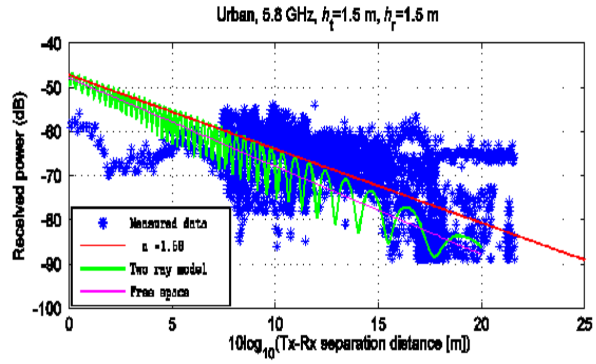

Fig. 8: Received power vs. $10\log_{10}(d)$ for urban scenarios [n=1.68]

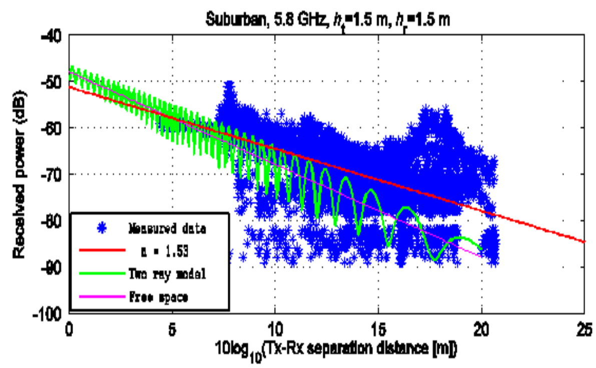

Fig. 9: Received power vs. $10\log_{10}(d)$ for suburban scenarios, [n=1.53]

[6] respectively. Larger values of Doppler shift between 761-978Hz has also been reported in [7].

For highway scenario,the authors in [1], [2], [3] and [5], who used the Log-distance power law model and obtained the mean pathloss exponent n of 1.77, 1.85, 1.80 and 1.90, respectively. The value of n=1.77 in [1] agree very well with our measured n value of 1.77 for the highway scenario. For the urban scenarios, the pathloss exponent are 1.61 in [2] and 1.68 [1]. Our mean pathloss exponent n=1.68 is the same as n in [1] for the urban scenario.

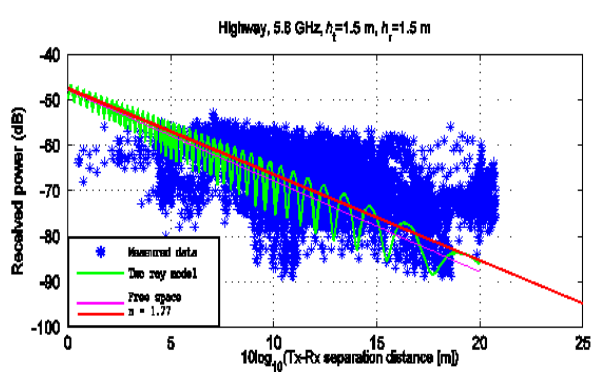

Fig. 10: Received vs. $10\log_{10}(d)$ highway scenarios [n=1.77]

TABLE IV: Comparing the proposed and the published Doppler spread and Path loss model parameters for different environments.

Scenarios	n	n^1	F_D	$F_D{}^1$	T_c
Highway	1.77	1.77 [1] 1.8 [3] 1.85 [2] 1.9 [5]	247Hz	92Hz [2] 120Hz [6] 761-978Hz [7]	1.57ms
Urban	1.68	1.68 [1] 1.61 [2]	149Hz	33Hz [2] 86Hz [6] 263-341Hz [7]	2.1ms
Suburban	1.53	1.59 [1] 1.57[4] 2.32-2.75[4]	162Hz	not reported	1.85ms

For Urban scenario, we evaluated an RMS Doppler value of 149Hz. However, different Doppler values of 33Hz in [2], 86Hz in [6] and (263-341) in [7] have been published. In the Suburban environment, we got a Doppler spread value of 162Hz. These discrepancies in the value of Doppler spread may be due to the different or charcteristics of cities and environments in different places or due to different measurement setup being used.

Fig.7 show that our urban scenario has a similar tendency as the two ray structure. Furthermore, in the suburban case, the reported pathloss exponent values are 1.59 in [1], 1.57[4] and 2.32-2.75[4] while our estimated mean pathloss exponent value is 1.53 for the suburban environment which is close to the value in [1]. These discrepancies in the values of the pathloss exponent show the strong dependence of pathloss on the selected propagation environment and on the measurement device and setup which motivates the need for further studies on V2V pathloss modeling.

In summary, our measurement data is closely related to the results obtained in [1] for highway, urban and suburban environments.

Also, it is evident that the following pathloss exponent values are outside the expected n range of 2 to 5 for the outdoor environments and are lower than the 2, which theoretically implies better propagation than free space. A pathloss exponent of less than 2 may occur due to constructive interference of multipath components; that is both LOS and reflected signals combine to give a better received signal. In other words, there is in addition to the LOS path, more energy available due to multipath propagation as indicated in [4]. This effect could be due to interference from devices and machineries operating at the same frequency as that of the DSRC radio which could result in more energy being added to the received signal.

V. Conclusion

We presented the result of empirical Doppler and pathloss model obtained in urban, suburban and highway environment under realistic driving conditions. Our presented Doppler parameters are based on experiment in [8] which takes into account the effects of moving objects particularly vehicles in oncoming lanes, owing to their large relative velocity and often close proximity. The differences in the values of the pathloss exponent for the urban, suburban and Highway scenarios shows the strong dependence of exponent on the specific propagation environment and measurement setup , this motivates the need for further studies. We observed great correlation between the separation distance and the relative speed of the transmitter (TX) and receiver (RX), which we suspect might be due to the tendency of the drivers to maintain greater TX-RX separation at higher speed. We observed that the Doppler spread are largest and the coherence time are smallest for the highway sceanrios. From the doppler and pathloss analysis, it could be inferred that the highway scenario is the worst case scenario for V2V propagation. The channel coherence time are much shorter than the typical packet duration, therefore the channel varies within one OFDM symbol, suggesting that further consideration is needed for a dynamic and optimum (doubly selective) channel estimation technique

Acknowledgment

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